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RECORDING OF ELECTRIC WAVES ON PAPER AND ITS FOUNDATION IN THEORY

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RECORDING OF ELECTRIC WAVES ON PAPER AND ITS FOUNDATION IN THEORY

By means of this method it is possible to chemically record on
white paper the presence of a multi-variable electrical field and also
the track of fall or passage of electromagnetic waves; consequently to
detect these without the aid of a galvanometer, thermoelectric couple,
or any other instruments with wires. The method consists of the use
of a detector of the short coherer type which is provided with elec-
trodes of different metals. The coherer lies on the paper and touches
it at two points. The paper is impregnated with an indicator sensitive
to current and which changes color as a result of electrolysis after
the waves strike the detector. The electrodes of the coherer can be
made from the same metals, but then it is necessary to pass through
the paper a current from a special battery. By distributing on the
sheet of paper many such detectors, each of about one centimeter in
length, after the waves strike (illumination by waves), the paper shows
the track of passage or strike of the rays in the form of colored spots
(stictography). A description is given of the electrostatics of the
stictographic detector, theory of plane current in a paper with a co-
herer lying on it, and the theory of static breakdown of a detector on
sensitive paper. The action of the latter is regarded from the point
of view of photographic sensitometry.

1. Sensitive Chemical Plate and its Use

For the recording of highly variable fields, writing paper is
used which had been first impregnated with a 0.1-1-percent solution of
phenolphthalein in alcohol and then moistened with a 20-percent solu-
tion of saltpeter or sodium sulfate. The paper is placed on a hair
sieve or on a thin sheet of ebonite (we used a sheet three millimeters
thick); on the edge of the paper are placed two brass rulers perpen-
dicular to the electrical vector of the waves (edge electrodes, Fig 1).

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They are introduced into a circuit of about 100 volts of direct current in series with a rheostat of 1000 ohms. Then a current of 20-50 milli-amperes flows through the paper.

The coherers seem to represent Braille tubes rolling on small wheels on the paper, the rotation of which replaces their shaking. The coherers consist of small glass tubes about six millimeters long and three millimeters in diameter. Short brass electrodes in the form of rivets d (Fig 1) are positioned in shellac in their ends. The distance between their internal surfaces is about two millimeters. It is half filled with slightly oxidized small brass shavings. During the operation, the axes of the coherers lie in the direction of the electrical vector of the waves. By rolling or throwing over the coherers along the paper when a current is passing through it during the operation of the vibrator, the paper shows red spots under the electrodes (heads of the rivets) of those coherers which lie in places of sufficient intensity of the electrical field of the waves. Obviously, the center of such a spot does not coincide with the center of the detector.

Having one—two tens of coherers, it is useful to sew these on in oblique rows to the thread net drawn on the light frame or to place these in the slots of the thin ebonite sheet, situated stepwise. The axes of the coherers thereby remain, of course, parallel to the electrical field. Such a frame or plate has the dimensions of about 10-15 centimeters, forming some kind of an "electrical cliche." In the course of its movement along the paper, all the coherers are at once displaced simultaneously.

In order to avoid the formation at the edge electrodes of large spots, it is useful during the stictographic process to commutate the direct current (Fig 1). /Illustrative material on the next page/ Each spot of the detector is displaced for half of its length with respect to the center of the section of the multivariable field which acts on the detector. This displacement takes place in the direction of the axis of the detector. In order to obtain accurate pictures of non-rectilinear fields, the latter circumstance should be taken into account and the waves should be played on the plate only for one kind of direction of direct current.

In order to reduce the wear of the vibrator or other source of the variable field, it is useful to include its feeding alternating current only for several seconds at the start of each completion of the direct current, for which there is a special switch on the axis of the commutator (Fig 1).

The operation of the coherers under the indicated conditions has the following characteristic. In ordinary shakers of old radio receivers it is possible to use coherers of the greatest sensitivity,
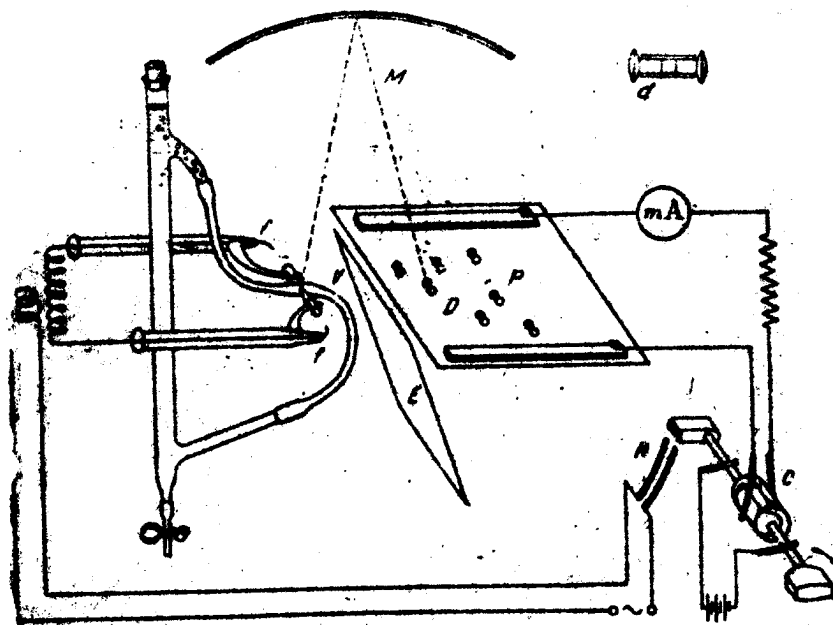
Fig 1

the conductivity of which lies on the limit and disappears only after several impacts of the shaker. Actually, the coherer gives the signal and the shaker operates until there is an unstable condition of the shavings, which disappears under the weakest action of electrical vibrations. Under real conditions, we select coherers of great strength, of the order of 20 volts, according to the measurements by E. G. Chernyavskaya, so that in the absence of vibrations, they should not give any spots on the paper. Hence, it is necessary to oxidize the shavings. The initial condition of such coherers is far from stable and, for this reason, their sensitivity is considerably less than the ordinary.

Despite this, it is possible to make photographs by using waves of insignificant energy and to obtain images of various objects, in particular to obtain a "photograph" of the diffraction spectrum of the electromagnetic waves. Such photographs, formed by dots, can be called stictograms and the method itself -- stictography (from the Greek στικτός -- speckled with spots).

2. Sources of Waves

Three types of the vibrator with spark excitation were used in the experiments described below.

In one case, it consisted of two cones V (Fig 1) positioned on glass horns of two tubes. The cones had on the apex rounded heads by

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means of which they were thrust into two diametrically opposite points into a thin rubber tube containing acetone (V. Arkad'yev. ZhRFKhO /Journal of Russian Physico-Chemical Society/, 44, 165, 1912; Ann. d. Phys. 58, 105, 1919.).

The second type represents two small cylinders screwed into an ebonite frame, secured with shellac at the ends of two glass tubes. All is placed in a third, wider tube about 10-12 millimeters in diameter and filled with kerosene (V. Arkad'yev. Zh.R.F.Kh.O., 45, 46, 1913; Ann. d. Phys., 45, 133, 1914.).

The third type of vibrator (Lebedev) consisted of two brass cylinders secured by shellac in the ends of two glass tubes on the axis of a parabolic mirror. The vibrator and mirror, located horizontally, were immersed in kerosene. The rays emerged vertically upward.

The described vibrators produced waves 20-100 millimeters in length. They were fed from a small Tesla transformer which gave two feeding sparks in the air 2-4 millimeters in length. In the primary circuit of the Tesla transformer, the spark gap was formed by four plates of the extinction spark (leshfunken) discharger from medical equipment for diathermy.

3. Photographs

1. Fig 1 shows the recording of the image of the Hertz dipole. The concave mirror M (Fig 1) with a radius of curvature of 25 centimeters and a diameter of 30 centimeters projects the vibrator V on the paper P. The optical adjustment of the axes and the adjustment for focus are accomplished optically by means of the light of feeding sparks ff.

The distance D from the vibrator to its image was 62 millimeters. The screen serves for the protection of the sensitive screen P against the direct action of the waves. The length of the vibrator was 12 millimeters and the wavelength was about four centimeters. The image of the vibrator, formed by the Hertz waves emitted by it, is shown in Fig 2 by means of spots of the darkening of the screen at the points of contact of the reacting detectors.

It follows from the theory of diffraction that the image of a luminous point in the focal plane of an astronomical tube represents a circle of brightness which decreases rapidly toward the edges and is surrounded by a system of diffraction rings considerably less bright. We shall designate the radius of the opening of the objective by r, its focal distance by l, the wavelength by λ and by δ the distance of the point under consideration, lying in the focal plane,

from the focus. We shall introduce

$$n = \frac{2 \varkappa r}{f \lambda}$$

The illumination in different points of a diffraction image will be designated by E and the illumination in its center by E_0. The following table lists the values of E/E_0 for different n (N. M. Kislov. Theory of optical instruments, page 53, Moscow, 1915.):

Table 1

n	0	1	1,6	2	2,2	2,7	3,2	3,8	5,2
$\frac{E}{E_0}$	1	0,7745	0,5075	0,3326	0,2554	0,1065	0,0265	0,000	0,0174
$\sqrt{\frac{E}{E_0}}$	1	0,8801	0,7124	0,5767	0,5054	0,3274	0,1633	+ 0,0067	— 0,1320

We see from this table that the brightness of the spot decreases to half for the distance determined by n = 1.6 when

$$\mathbf{l} = 0{,}355 \lambda \frac{f}{r}.$$

It changes into zero when n = 3.8 when

$$\mathbf{l} = 0{,}606 \lambda \frac{f}{r}.$$

At the maximum of the first diffraction ring, when n = 5.2, it amounts to less than two percent of the brightness in the center, while the amplitude is equal to 13 percent of the amplitude in the center. The diameter of the central spot 2δ is determined by the speed of the objective $2r/f$. Taking as the width of the spot Δ that diameter at the ends of which the energy falls to half ($E/E_0 = 0.5$), it can be determined that

$$\Delta = 1{,}4 \lambda \frac{f}{2r}. \tag{1}$$

We see that the width of the image of the point depends on the wavelength and speed of the objective and does not depend at all on its dimensions. In photographic objectives and astronomical tubes f/2r is frequently of the order of 5; for this reason, they give an image of the point with a width $\Delta = 7\lambda$. Let us assume that formula
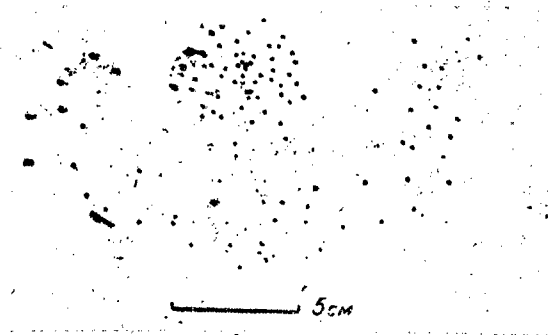
Fig. 2

(1) as a first approximation, is applicable also in our case. This is equivalent to the assumption that the threshold of sensitivity of the plate is $E = 0.5\ E_o$, see paragraph 4. For the width of the image, we find

$$\Delta = 1.4 \cdot 4 \cdot \frac{25}{30} = 4.7\ c.\text{m}.$$

This is not in poor agreement with experiment (Fig 2) where the central spot is surrounded by a ring of points. Fig 3 shows a summary

Fig 3

photograph obtained by the superposition on one another of ten such photographs. In order to investigate the distribution of the density of the points along the radius, the central spot was divided into concentric zones with circles of radii equal to 4, 8, 12,.. millimeters, the center of which was in the center of the optical image of the

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dipole. The number of points of each wave, divided by its area, is shown in Fig 4 by a solid line. The dotted line represents the distribution of the energy in accordance with the theory of optical diffraction from the circular opening, on the assumption that λ = 3.8 centimeters. In order to clarify the uniformities of the illumination of the zones in the different azimuths, each zone was divided into 18 sectors of 20 degrees each. By calculating the density of the small spots in each sector of a zone, it is possible to obtain curves of the distribution of the density along the azimuths (Fig 5), where the relative density is plotted along the radii.
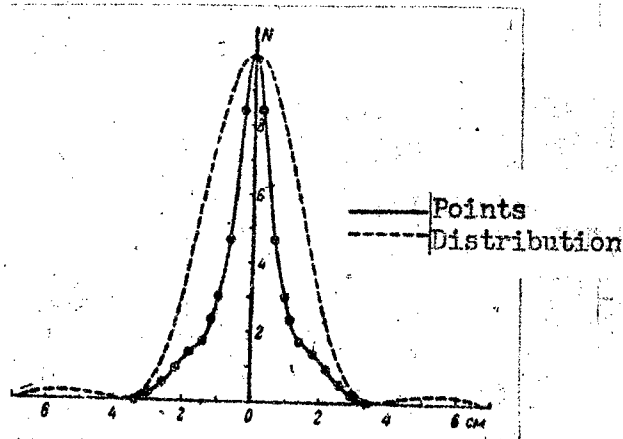

——— Points
------ Distribution

Fig 4

When the paper and the coherers lying thereon were positioned perpendicular to the axis of the vibrator, no traces of the action of the coherers were detected. This indicates a weakness of the perpendicular component of the electrical vector in the image of the dipole.
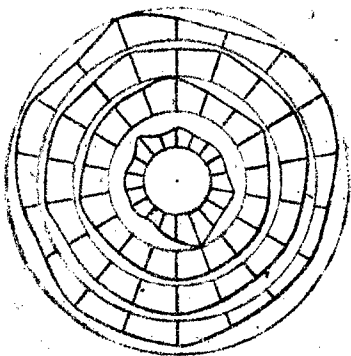

Fig 5

Photographs 2-3 and their processing were accomplished by A. M. Morozova.

2. Fig 5 shows a cross section of a bundle of rays of electromagnetic waves emanating from a horizontal Hertz mirror. The rays are intersected by a sensitive screen which is at a distance of 14 millimeters from the axis of the mirror. A reproduction of the resulting figure is shown in Fig 6. By placing in the path of the rays a paraffin lens, the cross section of the bundle becomes considerably narrower (Fig 7). At a distance of 17 and 22 centimeters, the photographs were alike.

3. Fig 8 shows the distribution of the instruments for photographing the diffraction spectra. For this purpose, a diffraction grating consisting of metallic strips 25 millimeters wide and situated 25 millimeters from one another was placed over the lens. Fig 8 shows

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the resulting points which represent one spectrum of zero order and two spectra of the first order. Straight lines are drawn through the resulting points; because of such hatching, the spectra of the different orders appear clearer and the different illumination in the different locations of the plate appears more vivid.
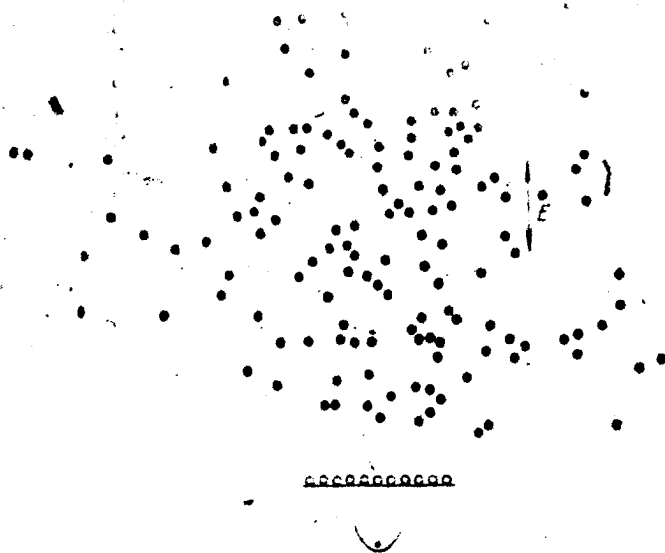

Fig. 6

The distance 2δ between the middle of the right and left spectra amounts to 25 centimeters, the distance d from the grating to the sensitive screen is 17.5 centimeters. The period of the grating $a = 5.0$ centimeters. Since

$$\lambda = a \sin \alpha = a \frac{\delta}{\sqrt{d^2 - \delta^2}} ,$$

then

$$\lambda = 5 \frac{12.5}{21.5} = 2.9 \ \text{cm}.$$

For the ratio of the wavelength to the length of the vibrator $l = 7$ millimeters, we obtain in this case
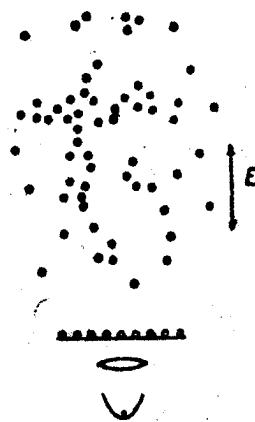
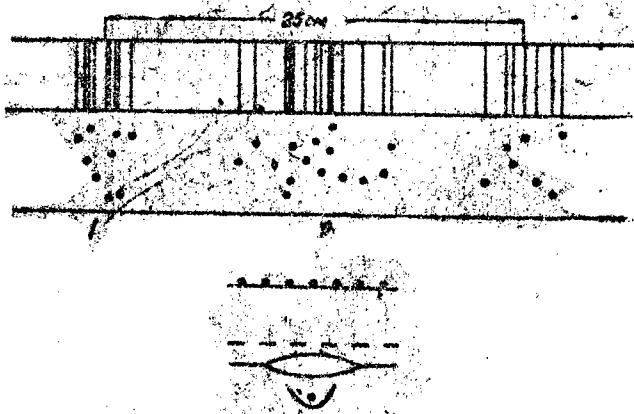$$\frac{\lambda}{l} = 4.1.$$

Fig 7

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Fig 8

The vibrator which is in the air has for such short waves a $\lambda/1$ of about three (V. Arkad'yev. Zh.R.F.Kh.O. 44, 165, 1912; Ann. d. Phys. 58, 105, 1919, Table 1; see also F. F. Nichols and J. D. Tear, Phys. Rev. [2] 21, 587, 1923.). In this case, it is immersed in kerosene (•—2) and for this reason, the ratio $\lambda/1 = 4.1$, close to $3 \cdot \sqrt{2}$ is quite acceptable.

4. The next three photographs represent a shade of an iron strip 27.5 millimeters wide, secured directly under the ebonite plate of the sensitive screen. Fig 9 shows the shade of a strip situated parallel to the electrical vector of the waves which emanate from the horizontal Hertz mirror (see Fig 6). As we see, the shade in this case has a width of 31 millimeters.
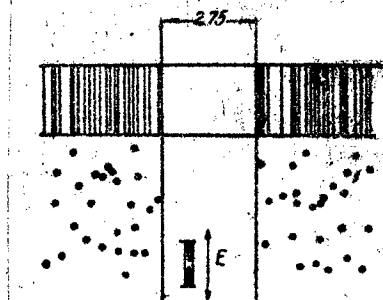

Fig 9

In Figs 10 and 11 the electrical vector is perpendicular to the axis of the strip. Fig 10 was obtained by means of detectors 13 millimeters in length, while in Fig 11 the detectors had a length of eight millimeters. This determines a much finer photograph and, for this reason, the width of the wave shade was obtained closer to the dimensions of the geometric shade -- 22 millimeters instead of 21 millimeters.

5. The shade of a coin 33 millimeters in diameter, cemented underneath the ebonite, is very weak. The key from an American lock acts stronger (Fig 12). The geometric shade of the key is outlined in the figure.
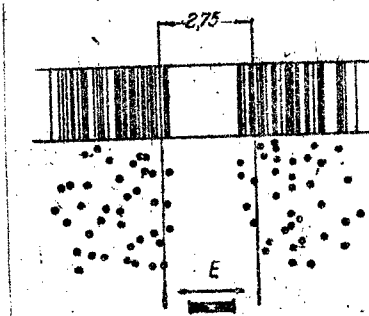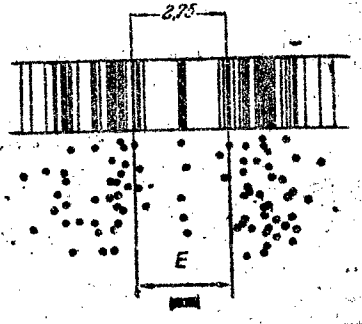
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Fig 10   Fig 11

6. Fig 13 shows the shade of a U-shaped glass tube filled with water and applied to the rear side of the sensitive plate; the distance from the source was equal to ten centimeters. The figures show the direction of the electrical vector of the waves.
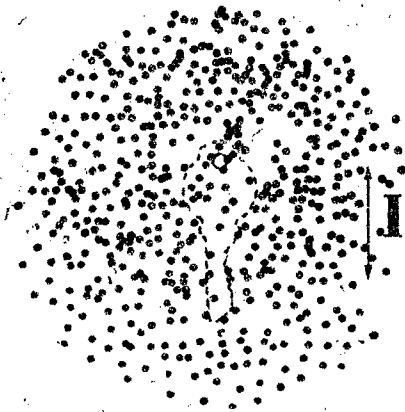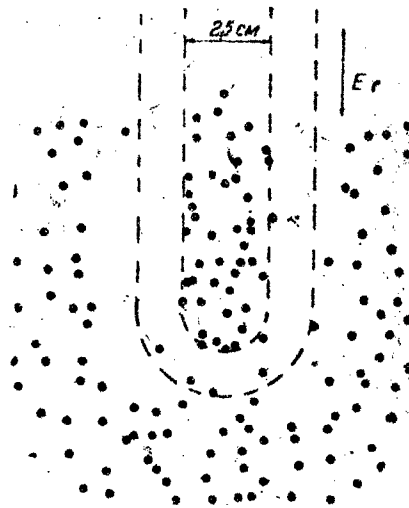
Fig 12   Fig 13

7. The shades of the hand of a woman and of the hand of a man are reproduced in Fig 14. The hand was placed under the sensitive plate. The wavelength of the Hertz rays in this experiment, just as in the preceding ones, was 2.9 centimeters. These photographs do not lay claim to accuracy. The fundamental possibility of obtaining such shades is of importance here. Because of the large wavelength, the outlines of the fingers are hardly noticeable.

8. Besides the cited photographs, diffraction images were obtained which were formed by a concave mirror having the form of a right triangle. The resulting spot had approximately the same dimensions as from a round mirror; its form was somewhat indicative of a

triangle. An image was also obtained from an asymmetric Hertz vibrator which consisted of two unequal sections: on one half of the

. Fig 14

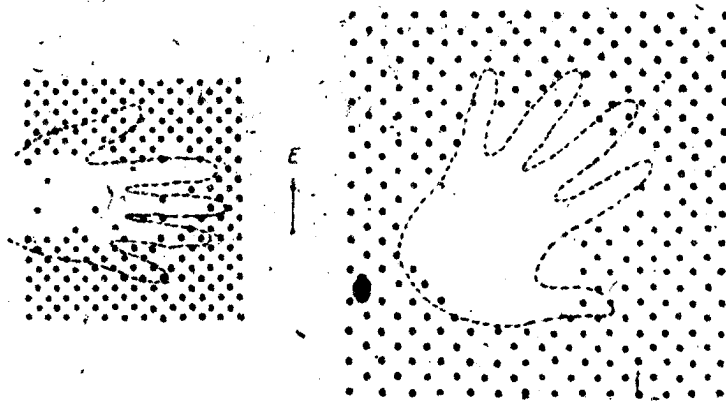vibrator (Fig 1) was placed a light copper tube about four centimeters long with a small flag at the end. The resulting image consisted of two superposed spots of earlier size. This indicated that emission proceeded from the ends of the vibrator and that the emitted waves had the earlier small length.

9. The method of coherers makes it possible to record also electrical fields of high frequency. Under the parallel wires of the Leher system in which standing waves are excited there is a long sensitive electrochemical plate with long edge electrodes parallel to the wires. The coherers are at a distance of several centimeters from the wires. In the antinodes of the waves, they leave spots on the paper. At the nodes, the paper does not turn dark. Photographs of such a type were reproduced without difficulty with an instrument for standing waves in wires in accordance with Drude and using a Blondlo vibrator. The waves had a length of 75 centimeters (observations by V. N. Azniyev).

4. Practical Applications

In the practice of research laboratories the described method of coherers can find the most diverse applications in the field of long waves as well as very short. This method can be used to investigate phenomena of diffraction of Hertz waves during their passage near different bodies, which can be used for the solution of problems of the distribution of high-frequency fields and rays in radio engineering, in problems of the application of ultrashort waves in

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medicine for the study of the penetration of the fields of meter waves into the human organism and many others.

The described method is the only means of graphic reproduction od the centers of electromagnetic radiation in complex vibrating system, so to say, the means of the perception of the sources of the Pointing vector. This confirms the described experiment with the a-symmetric vibrator which radiates with its ends the energy of its overtones. The method of chemical recording of electromagnetic radiation makes it possible to "photograph" the spectra of Hertz rays just as we photograph light and ultraviolet spectra.

X-rays make it possible to distinguish within bodies the portions which differ in density, for example the bones or metals within the tissues of an organism. In order to detect bodies of the same density, for example paraffin in water or water inclusions in paraffin or in oil, x-rays are of little use or no use at all. In these cases, in order to detect bodies which differ in electrical properties, use can be made of Hertz waves several centimeters in length, which, if the detectable bodies are not very small, can give on a chemical screen shades similar to images given by x-rays on a photographic plate. By this method it is possible to reveal in dielectrics hollow spaces or metallic bodies. This method makes it possible to speak about the detection of defects in dielectric shapes such as, for example, carbolite, ebonite, or porcelain insulators, castings of paraffin, etc. It can serve also for detecting layers of water in barrels with oil, tar, compound, etc. So far, it has been demonstrated that this method is applicable for laboratory work. With further development, it can find application, first of all, in those cases in which x-rays cannot be used. In comparison with these, it has a great advantage as regards simplicity of application and low cost of the apparatus: all operations are conducted in the light, while the sources of energy are extremely simple: induction coil which gives 30 kilovolts and direct current of several hundred amperes with 40 volts (Par 1).

Fig 15 shows uniform illumination of the plate by rays of the vibrator which produces waves three centimeters long. The waves passed
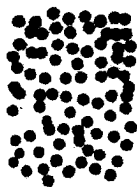
Fig 15   Fig 16   Fig 17

along the axis of a solid, continuous paraffin cylinder 15 centimeters high and 16 centimeters long. When a hollow space four centimeters in diameter was made in the cylinder, a shade was obtained as shown in Fig 16. Fig 17 shows the shade of the same hollow space containing water.

5. Theoretical Premises of the Method

A. Difference of Potentials Within the Coherer

When the coherer is in a variable electrical field, then, if its extinction from contact with a moist paper is not excessively large, it can resonate on the electrical vibrations; the length of their wave is close to the double or triple length of the coherer, if it resonates with a basic frequency. Resonance with overtones is also possible.

In case of resonance, the charges aimed at the ends of the detector can be greater than those which are aimed in more slowly changing (quasistatic) fields.

(a) In the last case, the charges can be approximately calculated as the electrostatic induction on two spheres connected with a long thin wire; up to the breakdown, the wire in the middle is cut and closed on the condenser of capacitance C, which represents the capacitance of the shavings-covered gap between the electrodes of the detector (Fig 18). The capacitance of the spheres represents the external capacitance of heads of the rivets of the detector, which we shall assume equal to their radius r. Let the quantity of electricity aimed at the spheres be q; this same quantity q is directed at the condenser; for this reason, the difference of the potentials of the spheres is q/C. The charges aimed at the spheres reduce to this value the difference of potentials U, which in the absence of the spheres was in two points of the field, at a distance equal to the distance of the centers of the spheres a. If the voltage of the field is E, then this difference of the potentials is $U = aE$. We shall assume for the simplicity of the calculation that the surface of the zero potential passes through the middle of the distance between the spheres. The potential at the place of the given sphere $U/2$ is compensated to $q/2C$:
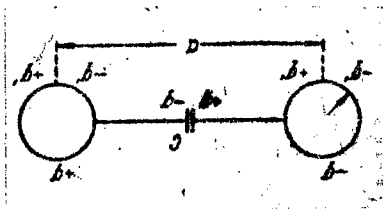

Fig 18

(1) by the potential of the charge of the given sphere q/r;
(2) by the potential of the charge of the adjacent sphere;
(3) by the potential of the charges of the dipole q', aimed at the adjacent sphere.

The dipole charge of the sphere from each of its side

$$q' = k \cdot \pi r^2 E',$$

where k is the susceptibility of the form of the sphere (V. K. Arkad'yev. Electromagnetic processes in metals, part 1, page 132, Moscow, 1935.), equal to $^3/_{4\pi}$, πr^2 is its cross section and $E' = E +$ voltage of the field produced by the adjacent sphere. The positive charge of the dipole is from its negative charge at a distance of 2/3 2r. The potential in the field of the given sphere of the dipoles increases by

$$\frac{q'}{a - \frac{2}{3}r} - \frac{q'}{a + \frac{2}{3}r} \cong \frac{r^3}{a^3} E'.$$

For this reason, the potential of the given sphere is

$$\frac{U}{2} - \frac{q}{r} + \frac{q}{a} + \frac{r^3}{a^3} E' = \frac{q}{2C}.$$

From this we find

$$q = Ea \frac{1 + 2\frac{r^3}{a^3}\frac{E'}{E}}{\frac{2}{r} - \frac{2}{a} + \frac{1}{C}}.$$

Disregarding the second member in the numerator and assuming 2/c = 2/r - 2/a, we find

$$q = \frac{Ea}{\frac{2}{c} + \frac{1}{C}}.$$

The difference of potentials between the electrodes of the detector we find equal to

$$\Im = \frac{Ea}{1 + 2\frac{C}{c}}.$$

It follows from this that the maximum difference of potentials is equal to Ea when C $\longrightarrow$ 0.

Presenting C in the form $c/(4\pi\delta)$, where c is the area of contact of the shavings and δ is the thickness of the insulating layer of

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oxides, we find

$$\vartheta = \frac{a}{1 + \frac{\sigma}{2\pi\delta c}} \cdot E.$$

We are interested also in the average concentration of the lines of force on the surface of the spheres, which can be regarded as the permeability of the form of the detector

$$m = \frac{4\pi q}{4\pi r^2 E} = \frac{a}{2r \left(1 - \frac{r}{a} + \frac{r}{2C}\right)} \cdot$$

If the internal capacitance of the coherer is very great, then

$$m = \frac{\Lambda}{1 - \frac{1}{2\Lambda}},$$

where

$$\Lambda = \frac{a}{2r} \cdot$$

Taking into consideration that the concentration of the lines of force on the right and left side of each sphere, taken separately, is equal to its permeability of form ϑ, we find the concentration of the lines of force on the external side of the spheres of our model

$$m_1 = m + \vartheta$$

and on the internal side

$$m_2 = m - \vartheta.$$

(b) The magnitude of the internal difference of the potentials can be calculated also if the detector is likened not to a pair of spheres but to a cylinder or ellipsoid having a susceptibility of form k. We assume that the cylinder is cut in the middle, perpendicular to the axis where there is a slot of capacitance C and width δ . C is so great that the distribution of the charges on the cylinder did not change its depolarizing coefficient N. However, the slot reduces the polarization of the cylinder in such a manner that the difference of the potentials ϑ which appears on the halves can be equated to the internal difference of the potentials between the poles of the cylinder of the dielectric with a certain dielectric permeability $\varepsilon = 4\pi k + 1$. By designating in such a cylinder the internal field by E_i and the distance between the poles by a', we find $\vartheta = a' E_i$. In the case of an ellipsoid, $a' = 2a/3$ while in the case of a cylinder, $a' \cong 5a/6$. By

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designating the surface density of the charges within the slot by I, we find that in the conducting cut cylinder $\vartheta = 4\pi I\delta$. In an equivalent dielectric cylinder, $I = E_i \varkappa$. Hence, $\varkappa = \frac{a'}{4\pi\delta}$. The susceptibility of the body of a cylinder is

$$\varkappa_\circ = \frac{k\varkappa}{k + \varkappa}$$

or

$$\varkappa_\circ = \frac{k}{1 + m\frac{\delta}{a'}},$$

where $m = 4\pi k$.

Here, m is the permeability of the form of a pierced coherer, i. e., the extent of concentration therein of the electrical lines of force when it is situated in a uniform field parallel to the latter. m is determined from the relative length of the coherer $\lambda = \frac{a}{d}$ and increases together with it. We determine m from special tables pertaining to magnetometric coefficients m of the cylinders; they are close to m of the ellipsoids. For a relative length of the detector Δ, approximately equal to three, its m amounts to about ten. For this reason, its susceptibility of the body $\varkappa_\circ$ is close to its susceptibility of the form k; in other words, the narrow slot $\delta \ll a/m$ in the cut cylinder decreases only insignificantly the charges aimed at it.

The charge on each half of the detector in the field E is $q = E\varkappa_\circ s$, where s is its cross section. The difference of the potentials is

$$\vartheta = \frac{q}{C} = m\frac{s}{\sigma}\delta E.$$

We see that in both cases considered (pair of spheres and cylinder) the potential ϑ will be greater the greater the length of the coherer, the greater the thickness of the layer of oxides ξ and the smaller σ, i. e., the transverse cross section of the shavings between its electrodes. The greater this potential and the smaller the disruptive potential of the coherer u, the more sensitive it is.

B. Distribution of the Current near the Detector

We shall examine an active detector, i. e., a detector with electrodes from different metals. It can be imagined that the area of the contact of the electrodes with the paper is limited by circles of small radius ρ, which are at a distance of a from one another, great in

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comparison with ρ . The resistance of the detector itself R_d is not great, for this reason, almost the entire difference of potentials is frequently applied on the resistance of the adjacent section of the sheet of paper. The latter is calculated from an examination of the distribution of the lines of the potential and density of the current in the sheet of paper. The problem reduces itself to the solution of the plane problem of finding the integral of the Laplace equation and coincides with the problem of the electrostatic field between two parallel wires (A. A. Smurov. High-voltage electrical engineering, page 33, 1932.). We shall call this problem the problem of the plane dipole. The resistance of the paper on which the dipole lies, for a small ρ , is equal to

$$R = \frac{1}{\pi \gamma \delta} \ln \frac{a}{\rho},$$

where γ is the specific electric conductivity of the paper and δ is its thickness.

The current in the active detector is

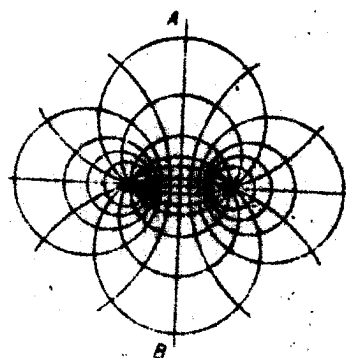$$i = \frac{\vartheta}{R + R_d},$$

where ϑ is its electromotive force.

The lines which show the direction of the current and the distribution of the potential are shown in Fig 19. The first represent the circles which rest on two points lying within the circles of contact of the electrodes with the paper. The equipotential lines are essentially the circles which have as a diameter the distance between the two points harmonically dividing the distance between the electrodes in an internal and external manner. The lines of equal density of current are essentially lemniscates. At a great distance, they encompass both contacts. If $a > \delta$, which always takes place in our case, at small distances the lemniscates break down into two egg-shaped curves.

Fig 19

When we have a passive detector, i. e., a detector with electrodes from like metals, then we are, first of all, interested in the electromotive force ϑ between the points of the paper, which are at a distance of the electrodes of the detector. If the density of the current in the paper is

$$J = \frac{I}{b\delta},$$

where I is the current in the sheet of paper of width b and thickness δ , then

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$$\vartheta = J\frac{a}{\gamma}.$$

In order for the current to pass through the detector, this magnitude should be greater than the electromotive force of polarization ϑ_p, because otherwise, the electrolysis will not take place. Its speed and the speed of formation of the spots will be greater the greater $\vartheta - \vartheta_p$ and the current in the detector i.

In the paper at the electrodes of the passive detector, because of its small resistance, the difference of potentials is equal to the electromotive force of polarization ϑ_p. Hence,

$$i = \frac{\vartheta - \vartheta_p}{R + R_d}.$$

This means that the current which causes electrolysis at the electrode increases with the density of the current of the battery J and the length a of the detector.

The picture of the field in the case of the passive detector is obtained by the superposition of the active detector on the uniform field of density of the external current. Fig 20 shows such a diagram, constructed by V. A. Kizel' in accordance with Maxwell method by adding the potentials in different points (V. A. Kizel'. ZhETF /Journal of Experimental and Theoretical Physics/, in print.). The photograph of an active field of the detector, lying on the paper, was obtained by Panasenkov in accordance with the Zinger method (A. Zinger. ZS. d. Ph. u. Ch. Unterr. 13, 336, 1900. I am indebted to professor A. I. Bachinskiy for the reference to this work by A. V. Zinger. The study of the method by A. V. Zinger is dealt with in a special investigation by F. F. Panasenkov. ZhETF 6, 457, 1936.).

In order to calculate the field near the passive dipole, we shall examine the electrostatic problem of two parallel cylinders connected electrically and introduced into a uniform electrical field E (An analogous problem for two spheres was solved by A. A. Petrovskiy. Izv. I. Pr. Geoziki VZNKh /News of the Institute of Applied Geophysics of the Supreme Soviet of the National Economy/, No 1, 1925, No 2, 1926.). At a distance a, there is action by the difference of potentials $\vartheta = Ea$ which is neutralized by the charges $\pm q$, aimed onto the cylinders; the charges give the difference of potentials $-\vartheta = q$ where $C = 1/(4\ln a/\rho)$ the capacitance between the cylinders, which is at one centimeter of their length. Hence,

$$q = \frac{Ea}{4\ln\frac{a}{\rho}}.$$

From one centimeter of the length of the positively electrified cylinder there is a stream of electrical lines

$$\Psi = \frac{\pi a}{\ln \frac{a}{\rho}} E.$$

For a case of two disks lying on moist paper, the current i passing through their connecting wire is $\gamma \delta \Psi$; hence,

$$i = \frac{\pi a \gamma \delta}{\ln \frac{a}{\rho}} E.$$

Noting that $\gamma \delta E$ is the density of the current in the paper J, we find

$$i = \frac{\pi a}{\ln \frac{a}{\rho}} J.$$

The average density of the current on the circumference of each disk is

$$J = \frac{i}{2\pi \rho}.$$

Since each disk individually concentrates the lines of current twofold (transverse permeability of the form of a cylinder (V. Arkad'yev. Electromagnetic processes in metals. part 1, page 135, Moscow, 1935.) m = 2), then the density of the lines of current with the external side of the disks is

$$\frac{i}{2\pi \rho} + 2J,$$

and with the internal

$$\frac{i}{2\pi \rho} - 2J.$$

By designating this coefficient for J by the letter m_1 and correspondingly m_2 we find

$$m_1 = \frac{A}{\ln 2A} + 2$$

and

$$m_2 = \frac{A}{\ln 2A} - 2,$$

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where

$$\Lambda = \frac{a}{2\rho}.$$

On the basis of this formula, it is possible to calculate the concentration of the lines of current for a plane dipole with $\Lambda = 35$, shown in Fig 19 where the distance between the centers of the dipoles is equal to 14 centimeters and their diameter 0.4 centimeters. In a uniform field, the distance between the lines of force is equal to one centimeter.

$$m_1 = \frac{35}{2{,}3\,\lg_{10} 70} + 2 = 10{,}25, \quad m_2 = 6{,}25;$$

in Fig 19 the dipole encompasses nine lines of the field.

The field formed by each of the cylinders separately at a distance of r from its axis is

$$E_1 = \frac{V}{2\pi r} = \frac{a}{2r\ln\frac{a}{\rho}} E.$$

Its natural polarization (V. Arkad'yev. loc. cit. page 132, equation (234)) gives from opposite sides charges for one centimeter of length

$$q' = \frac{2 \cdot 2\rho}{4\pi}(E - E_1) = \frac{\rho}{\pi}\left(1 - \frac{1}{2\ln\frac{a}{\rho}}\right)E,$$

which for large r can be considered concentrated within the cylinders on two lines which are at a distance (V. Arkad'yev. loc. cit. page 132, equation 234)) of $2/3 \cdot 2\rho$. On the plane passing through these lines, the field is equal to

$$\Delta E = q'\left(\frac{2}{r - \frac{2}{3}\rho} - \frac{2}{r + \frac{2}{3}\rho}\right),$$

approximately

$$\Delta E = \frac{8}{3}\frac{q'\rho}{r^2}.$$

Substituting q', we find

$$\Delta E = \frac{8}{3}\frac{E\rho^2}{\pi r^2}\left(1 - \frac{1}{2\ln\frac{a}{\rho}}\right)$$

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Between the two cylinders the field formed by them is $E' = 2E_1 - 2\Delta E$ or
(This same formula can be obtained from the expression of the potential
near two cylinders, which was derived by V. A. Kizel' (equation (11),
loc. cit.) from more general considerations also for any point of the
plane when $R > 5\rho$. The difference is exhausted by the coefficient near
the parentheses, which, in the case of Kizel', was equal to one instead
of $8/(3\pi)$.).

$$E' = \left[-\left(\frac{1}{r_1} - \frac{1}{r_2} \right) \frac{a}{2 \ln \frac{a}{\rho}} + \frac{8\rho^2}{3\pi} \left(\frac{1}{r_1^3} + \frac{1}{r_2^3} \right) \left(1 - \frac{1}{2 \ln \frac{a}{\rho}} \right) \right] E \qquad r_1 = -r_2 = a/2,$$

In the middle between the cylinders, when

$$E' = -E \left[\frac{2}{\ln 2\Lambda} - \frac{64}{3\pi} \frac{\rho^3}{a^3} \left(1 - \frac{1}{2\ln 2\Lambda} \right) \right].$$

For the case $\Lambda = 35 E - E' = 0,529 \ E.$

The field between the cylinders is equal to zero at a certain
point $r_1 = a - r_2$, when $E' + E = 0$ and

$$\frac{a^2 r}{2 r_1 r_2 \ln \frac{a}{\rho}} - \frac{8\rho^2}{3\pi} \frac{r_1^2 + r_2^2}{r_1^3 r_2^3} \left(1 - \frac{1}{2 \ln \frac{a}{\rho}} \right) = 1.$$

From this it is possible to find

$$r_1 = \frac{a}{2} \left(1 \pm \sqrt{1 - \frac{2 - \frac{4\rho}{a}}{\ln \frac{a}{\rho}}} \right).$$

In our example of Fig 20, it is possible to find that the field
between the electrodes changes into zero at two points: r_1 = 19.2 mil-
limeters and r_1 = 121.8 millimeters.

C. Grain Size of Stictographic Photographs

By grain size of the photographic plate
are understood the dimensions of the aggre-
gates of the darkened small crystals of silver
bromide which form the individual groups.
Each small crystal has the size of about one
micron; consequently, it is two-three times
greater than the length of the incident wave;
the aggregate of the small crystals which are
in chemical contact and, for this reason, si-
multaneously darkened in the developer has
the dimensions of hundredths of a millimeter.
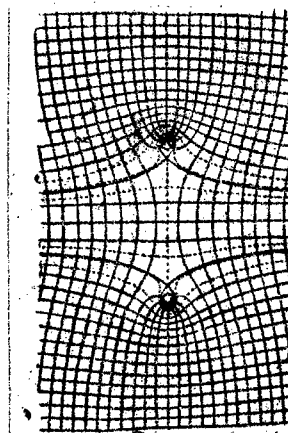For this reason, the boundary of the resolving

Fig 20

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capacity of an ordinary photographic plate amounts to 0.02 - 0.03 millimeters.

This magnitude is distinguished by the eye at a distance of clear vision equal to 20-30 centimeters because the resolving force of the eye is about 1/1500 radians or almost two-minute angle. Thus, the dimensions of the aggregates exceed by several tens the wavelength which causes the darkening.

In a sensitive layer, the individual aggregates lie in several rows one above the other and shield partly each other from the light rays passing through the negatives. This explains why the plate in dark places can sometimes not pass light at all.

Under the conditions of our photographs, which were made by means of Hertz waves, the role of the aggregate which absorbs the waves is played by the coherer. Its dimensions with respect to the length of the wave are not great, amounting mostly to $\lambda/3$. Consequently, it is relatively smaller than a crystal. The coherer does not leave on the paper a track equal to it in size; the track is a little larger than the area of contact of the electrode with the paper (circle $\varnothing$ 0.8 millimeters). The density of the layer of our photographs is, for this reason, very small.

In photographing large parts (large shades or images), the photograph does not lose accuracy, if the track on the paper forms an area equal to or even greater than the projection of the coherer on the paper.

Such magnified tracks are sometimes produced by us intentionally by forming with a rubber stamp round spots on the points left by the detector on the paper. In this manner, we find it possible to cover with a color the greater portion of the paper with a small number of contacts (Fig 14). The photographs obtained up to now are small with respect to the area, amounting to not more than several units or tens of square wavelengths. In ordinary photography such photographs cannot even be obtained because they are all positioned on one aggregate of crystals of silver bromide. They could be made only on very fine-grained layers such as the layers in Wiener or Lipman plates which photographed the standing light waves that formed within the layer.

D. Sensitometric Chemical Plate

A coherer, as is known, is a very sensitive and very unreliable detector. However, this is a quality of the individual coherer. In this case we are making use of several coherers simultaneously and

we compel such a group of coherers to act repeatedly, covering the paper many times with detector spots. Such a statistical utilization of the coherer makes it possible to use it not only for qualitative observations. An old coherer rejected for individual utilization can again appear in the technique as a statistical coherer.

We shall now examine the quantity of spots, i. e., the darkening of the paper, as a function of the intensity of the incident energy, i. e., of the illumination of the plate by Hertz waves E. The darkening of the paper depends on the number of spots per square centimeter of paper. Let the contact spot in the middle have an area s; sometimes we place on the photograph with a stamp a black circle for each spot; we designate its area also by s. If the spots are rare and one circle does not touch another, then the darkening of the paper will be determined by the ratio $Ns/S = q$, where N is the number of circles on the area of the paper S. We wish to note that in photographic sensitometry the coefficient of darkening O of the photographic layer (opacity) is called the ratio of the brightness of the section without decomposition products to the brightness of the section with decomposition products; for a small q,

$$O = \frac{S}{S - Ns} = \frac{1}{1-q} \cong 1 + q.$$

The optical properties of the layer are evaluated by its optical density which is taken as $D = \lg_{10} O$.

Since $\lg_{10} O = 0{,}4343 \ln O = 0{,}4343 \left(q - \frac{q^2}{2} + \frac{q^3}{3} \cdots \right)$, then for small q's, the density is $D = 0{,}43 \, q$.

If the coherer goes into action under the influence of an instantaneous difference of potentials u_o, then all the values less than u_o do not act on it; the greater ones act just as the maximum difference of the potentials u_o; we shall call it the threshold of the sensitivity of the detector. Each detector is characterized by its threshold u_o which, for each coherering, can have different values. Experience shows, however, that for u close to u_o, the number of coherering detectors during the time of the photography gradually increases with the time of operation of the vibrator, which indicates the influence also of the quantity of energy of radiation that fell on the paper. For this reason, in the factor u_o, perhaps one should also consider the energy radiated onto the detector. We assume that these values of u_o are distributed between certain u_1 and u_2 in accordance with the law of chance and that the probability of the appearance for the given completion in the given coherer of the value u lying between u_o and $u_o + du_o$ can be represented in the form of the expression

$$P_0 \cdot du_0 = f(u_0) \cdot du_0.$$

Let the illumination in a certain section of the sensitive plate be E; it corresponds in the coherer to the value of the factor u. For a large number of coherers n and completions m, the number of coherering detectors is

$$N = nm \int_0^u f(u_0)\, du_0.$$

N, and with it q and D, is a function of u which has the shape of an inclined curve which bends to the abscissa axis. This curve is made parallel to the axis for the greatest values of u_2 which can only be encountered in individual coherers.

This means that the density D or the measure of darkening of the plate q in a certain region u, between certain u_a and u_b, depend linearly on the illumination E; for small E's lying below the threshold u_1, the plate does not change under the action of illumination. In this respect, our plate is similar to a photographic plate which also has a threshold of sensitivity. In a certain region u and correspondingly E, we can examine the dependence of D on E as linear. This is the region of the proportional increase of the density with the illumination. In this region, which in photography is called the width of the emulsion, photographs are obtained with the most correct transfer of the original.

Ordinarily, the width of an emulsion is measured by the difference of the logarithms of the corresponding exposures. If the law of the distribution of u_0 near its most probable value is determined by the distribution curve shown in Fig 21b, then the "width of the emulsion" of the electrochemical plate, evaluated by the difference $\lg_{10} E_b - \lg_{10} E_a$, is very small, of the order of 0.2. This corresponds to the ratio $E_b/E_a = 1.6$; consequently, to a very rapid rise
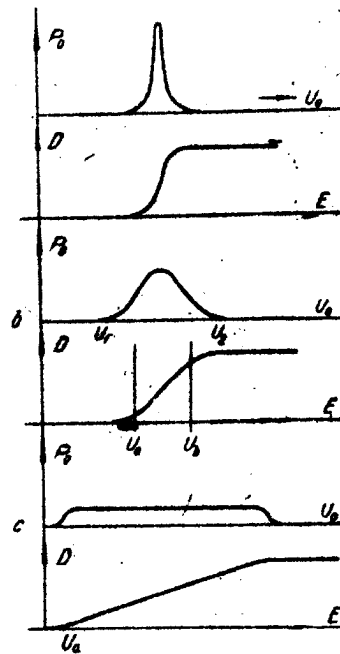
Fig 21

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$$\frac{D_2' - D_1'}{\lg_{10} E_2 - \lg_{10} E_1}$$

or a great contrast τ of the photograph in this region; in photographic sensitometry

$$\gamma = \frac{D_2 - D_1}{\lg_{10} E_2 - \lg_{10} E_1} .$$

This contrast τ or the density gradient

$$g = \frac{dD}{d \lg_{10} E}$$

can be made very large by selecting the coherers with u_a as close as possible; when $u_b - u_a$ is very small (Fig 21a), such a plate should be used for photographs with image sections that differ in brightness, i. e., with weak half tones.

For strong and uniformly scattered values of u_0, we obtain a very large "width of emulsion" (Fig 21c), which becomes necessary if it is desired to fix the half tones in weak as well as in dark sections of the image (See V. Arkad'yev and E. Chernyavskay. ZhETF; 7, 107, 1936 (see below)).

6. Conclusions

While we can note the following features of similarity and difference between the electrochemical (stictographic) and photographic sensitive plates:

1. A chemical sensitive plate permits fixation of such phenomena as electromagnetic radiation which cannot be picked up by any other method in the form of a graphic image.

2. It permits momentary photographs, i. e., it is capable of fixing extremely brief electrical phenomena.

3. It has a threshold of sensitivity and can have a greater or smaller "width of emulsion."

4. It reacts essentially on the amplitude of the field and not on its energy; for this reason, a chemically sensitive plate is not capable of accumulating the action of radiation and has a high limit of sensitivity.

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5. Its grain comprises a fraction of the length of the record-ed waves; for this reason, the accuracy of the photographs, in the sense of the transfer of small details close in dimensions to the wave-length, is much greater than that of a photographic grain.

6. The electrochemical plate is anisotropic and has an axis of the greatest sensitivity. In a perpendicular direction, it does not pick up electrical vibrations.

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